



Evaluation of soil and water conservation practices in the north-western Ethiopian highlands using multi-criteria analysis

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Investments by farmers in soil and water conservation (SWC) practices are influenced by the physical effectiveness, financial efficiency, and social acceptability of these practices. The objective of this study is to evaluate different SWC practices in the north-western highlands of Ethiopia using various qualitative criteria and weightings based on ecological, economic and social impacts using Multi-Criteria Analysis (MCA). The study reveals that MCA is a useful evaluation tool that takes into account non-monetary and less quantifiable effects of SWC practices. Farmers employ a range of criteria to evaluate the performance of SWC practices. The relative importance of each criterion in their selection of SWC alternatives depends mostly on slope categories. In steeply sloping areas, farmers assigned the highest score for criteria related to ecological impacts; whilst preferring practices with stronger positive economic impacts in moderate and gentle sloping areas. Policy makers and development practitioners are encouraged to pay greater attention to both farmer preferences and slope specific circumstances when designing SWC strategies and programmes.

Keywords: multi-criteria analysis, soil and water conservation, farmer preferences, slope, Ethiopia

INTRODUCTION

Agriculture is the major source of livelihood in Ethiopia. However, land degradation in the form of soil erosion has hampered agricultural productivity and economic growth of the nation (Hailelassie et al., 2005; Hengsdijk et al., 2005; Balana et al., 2010). Land degradation, low agricultural productivity and poverty are critical and closely related problems in the Ethiopian highlands (Pender and Gebremedhin, 2007; Yitbarek et al., 2012).

Investments¹ in soil and water conservation (SWC) practices enhance crop production, food security and household income (Adgo et al., 2013). Recognizing these connections, the government of Ethiopia is promoting SWC technologies for improving agricultural productivity, household food security and rural livelihoods. Particularly in the Ethiopian highlands, different SWC technologies have been promoted among farmers to control erosion. These technologies include stone bunds, soil bunds and *Fanya juu* bunds (made by digging a trench and moving the soil uphill to form an embankment). However, the adoption rates of these SWC technologies vary considerably within the country (Kassie et al., 2009; Tefera and Sterk, 2010; Tesfaye et al., 2013; Teshome et al., 2014), largely because investments by farmers in SWC are influenced by the ecological, economic and social impacts of the SWC technologies.

The impact of SWC measures in Ethiopia and elsewhere is mostly evaluated in monetary terms (cost-benefit analysis; CBA) (Bizoza and de Graaff, 2012; Teshome et al., 2013). However, SWC measures also have ecological and social impacts that cannot be easily quantified in monetary values (Tenge, 2005). Moreover, CBA is sometimes criticized in that it does not take into account the interactions between different impacts. More rigorous evaluation methods of SWC measures are of paramount importance in quantifying the monetary and non-monetary value of SWC measures to ensure better decision-making processes of policy makers and development practitioners.

Availability of several SWC alternatives, conflicting objectives and a range of evaluation criteria of farmers hamper their decision-making and adoption of SWC measures (Amsalu, 2006). Farmers' investment objectives often differ considerably from those of researchers and extension personnel, as they have other objectives in addition to reducing soil loss and maximizing financial benefits of SWC measures (Tenge, 2005). These objectives are often conflicting, resulting in no single SWC measure that can provide the best outcome for all farmers.

Therefore, there is a need to evaluate the objectives and criteria of farm households in decision-making of SWC practices based on ecological, economic and social impacts. In order to identify and analyse multiple and conflicting objectives and goals, Multi-Criteria Analysis (MCA) represents a more suitable tool (Romero and Rehman, 2003). In addition, MCA methods are an appropriate modeling tool for addressing economic-environmental

¹ Investments refer to any efforts (e.g. labor, knowledge, and time) made by farmers to combat water erosion and enhance soil fertility.

evaluation issues (Munda et al., 1994; Mendoza and Martins, 2006).

The objective of this study is to evaluate different SWC practices using qualitative criteria by different stakeholders (farmers and experts) based on perceived ecological, economic and social impacts.

MULTIPLE CRITERIA ANALYSIS (MCA) FOR SOIL AND WATER CONSERVATION EVALUATION

Most SWC investment activities are evaluated using a CBA, which assumes that complex soil and water objectives can be converted into one basic objective of “maximizing profit.” However, the objective function consists of a single choice criterion, yet within SWC investments, there are usually several objectives or goals (Prato, 1999). Therefore, a discrete MCA has been developed as a decision-making tool when different objectives have to be fulfilled. Recently, Fleskens et al. (2014) revealed that scenario assessments with integrated models help determine location-specific, financially viable technologies to effectively combat land degradation problems, and provide input into multilevel land management decision-making processes. Moreover, choice experiments, a stated preference valuation method, are also a tool that can assign monetary values to environmental impact assessment (Vega and Alpizar, 2011).

MCA is a decision-making tool applied to choice problems in the face of a number of different alternatives and conflicting criteria (Hajkowicz et al., 2000). CIFOR (1999) defined MCA as a decision-making tool developed for complex multi-criteria problems that include qualitative and/or quantitative aspects of the problem in the decision-making process. MCA is an evaluation method, based on sustainable development economic theory, that ranks or scores the performance of decision options against multiple criteria (Hajkowicz, 2007), ensuring the final results have clear meaning in terms of sustainability (Boggia and Cortina, 2010).

The main characteristics of MCA are: multiplicity of objectives, heterogeneity of objectives and plurality of decision makers (Seo and Sakawa, 1988). However, in terms of evaluating SWC practices, MCA has some advantages and disadvantages (de Graaff, 1996; Prato, 1999) (Table 1), but offers great potential in addressing the shortcomings of other SWC evaluation methods.

For evaluation of SWC investments, CBA only compares one “with” case with one “without case” (or “before” and “after” case), resulting in all effects being valued in monetary values, and focused mostly on the efficiency criterion. MCA has the disadvantage that it does not allow for an easy comparison of streams of costs and benefits over time, and relies on subjective weightings attached to several criteria by the stakeholders concerned and represented (Table 1). An appropriate solution to evaluate SWC is the use of CBA results as one of the criteria (efficiency) in the MCA evaluation of SWC measures (de Graaff, 1996). Therefore, MCA appears to be one of the more appropriate tools to evaluate SWC practices.

STEPS IN MULTI-CRITERIA ANALYSIS (MCA) METHODS

MCA uses a number of defining steps to identify the best alternatives on the basis of relevant criteria (Voogd, 1982; Munda et al.,

1994; Tenge, 2005; Hajkowicz and Higgins, 2008; Ananda and Herath, 2009). The major steps in the MCA are the following:

- Step 1: Determination of objectives.
- Step 2: Identification of alternatives/options, that contributes to achieving the objectives.
- Step 3: Determination of the evaluation criteria to assess the performance of the alternatives.
- Step 4: Determination of the effects (score) on alternatives. The effects of alternatives are identified, measured (quantitative or qualitative) and determined according to the measurable criteria set, established in step 3.
- Step 5: Standardization of the effects. Making the unit of scores comparable, on a scale between 0 and 1, eliminates the effect of different dimension scoring of alternatives.
- Step 6: Formulation of weights. Weights are assigned to criteria by farmers, policymakers, or other stakeholders to represent their relative importance for the respective group.
- Step 7: Aggregation and ranking. Involves combining weighted scores for each alternative. Among the discrete MCA methods, the most important aggregation methods are the Additive Weighting and the Sequential Elimination methods.

MATERIALS AND METHODS

STUDY AREAS

The study was undertaken in three watersheds in the East and West Gojam Zones of the Amhara region of Ethiopia, i.e., the Anjeni, Dijil, and Debre-Mewi watersheds (Figure 1). The watersheds are part of the north-western highlands of Ethiopia. These watersheds were selected because of their specific experience with SWC activities. Moreover, the watersheds have diverse

Table 1 | Advantages and disadvantages of MCA for evaluating SWC.

Advantages of MCA	Disadvantages of MCA
Focus on several objectives and alternatives.	Non-comparability among objectives.
Considered the intangible effects of SWC.	Exposed to subjectivity problem: subjective weights attached to several criteria.
Use of both qualitative and quantitative effects.	Use of qualitative scales, where quantitative could be used.
Holistic approach: it can also incorporate CBA and other financial efficiency criteria.	Different methods give different results.
Increases the rationality of the decision process.	Difficult to incorporate the time dimension.
Identifies gaps in knowledge in SWC practices.	Pays little attention to uncertainty and to possible trade-offs among some of the objectives.
Interactive method.	Different conflicting evaluation criteria are taken into consideration.

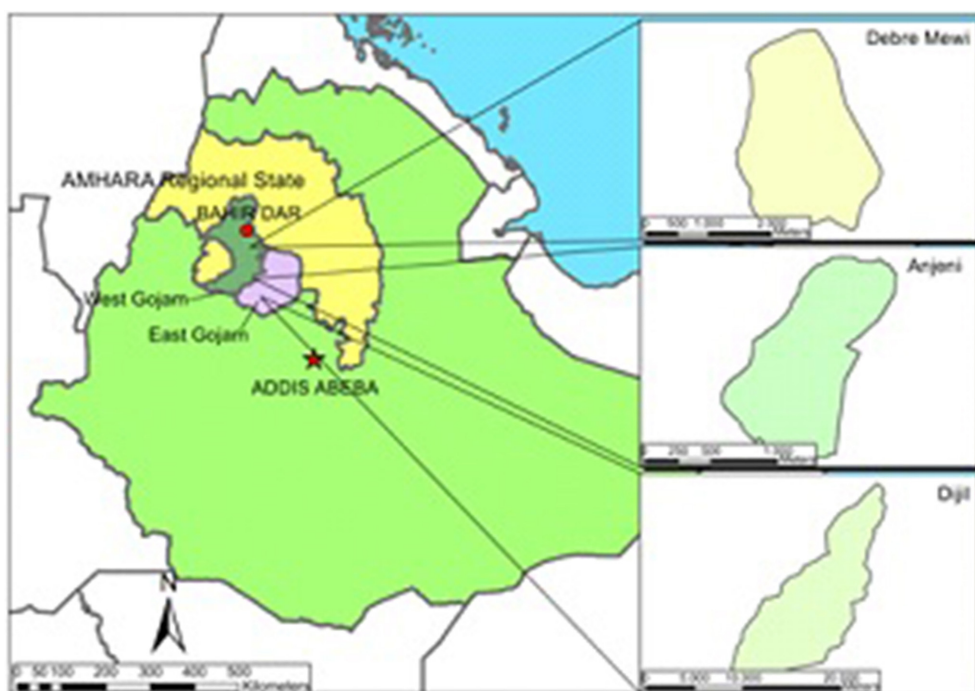


FIGURE 1 | Map of study areas in Amhara regional state, Ethiopia.

biophysical and socio-economic characteristics (Table 2). The dominant farming system in the watersheds is characterized as crop-livestock mixed farming.

DATA COLLECTION

Farmers and experts are the main stakeholders in SWC activities in the Ethiopian highlands. Qualitative and quantitative data were collected from these stakeholders using group discussions and a formal survey in 2013. Two group discussions were undertaken in each watershed. The number of participants in each group ranged from 9–11 farmers. Group discussions were followed by an individual survey to crosscheck the information provided. For this survey a total of 50 farm households (20 from Debre Mewi, 15 from Anjeni and 15 from Dijil) were carefully selected from an earlier much larger household survey². In addition, 16 experts were interviewed from different levels of the Department of Agriculture (*kebele*³, district, zone, and region).

SWC alternatives and evaluation criteria were identified during the two previous surveys and group discussions (Teshome et al., 2014, Forthcoming). SWC alternatives and evaluation criteria were compiled and presented for discussions with farmers. During the group discussions, some SWC alternatives and criteria were removed as they were either not very relevant, or not commonly practiced in the prevalent farming system

(alternatives and criteria were fine-tuned during group discussions). For example, for farmers in Anjeni, soil bunds were not important in their watershed. Thus, weightings were reassigned through group consensus to criteria dependent on the different slope categories (steep, moderate, and gentle). This is because farmers mainly classify their land parcels into three categories, i.e., steep (*tedafat*), moderate (*mekakelegna*), and gentle (*deledala/medama*). A fixed point scoring technique was applied in this study (Hajkowicz et al., 2000), where the decision-maker is required to distribute a fixed number of points among the criteria. Thus, a higher point score indicates that the criterion has greater importance. Fixed point scoring is the most direct means of obtaining weighting information from the decision maker.

SOIL AND WATER CONSERVATION ALTERNATIVES

SWC measures are part and parcel of the farming system evident in the study areas. Almost all farmers perceived erosion problems while many of them also believed that SWC measures are profitable (Teshome et al., 2013). Thus, different SWC measures to avert erosion problems were introduced by government and non-government organizations. Soil bunds, *Fanya juu* bunds and stone bunds are the major SWC measures that are widely implemented by farmers. Therefore, these three SWC measures and the “No measure” alternative were included in the evaluation.

Soil bunds

Soil bunds are embankments made from topsoil along the contour to control erosion (Figure 2). They require less labor for

²These 50 farm households are part of large survey of households. This large survey included 60, 125, and 115 households from Anjeni, Dijil, and Debre Mewi watersheds, respectively.

³*Kebele* is the lowest administrative body in Ethiopia and is part of the sub-district.

construction compared to stone and *Fanya juu* bunds as excavated material from the ditch is placed downhill rather than uphill, as is the case in the construction of *Fanya juu* bunds. However, soil bunds require more labor for maintenance than *Fanya juu* and stone bunds. The uphill drains of the soil bund are impacted by accumulated material (silt) and therefore require more labor to regularly excavate the ditches, as farmers need to ensure effective evacuation of excess water. Grass is grown on the riser to stabilize the bunds. Soil bunds can be easily eroded during heavy rainfall in steeply sloping areas.

Fanya juu bunds

Fanya juu bunds are made by digging a trench and moving the soil uphill to form an embankment (Figure 2), and are thus more labor-intensive during construction. A terrace can therefore be created in a relatively short period of time. They provide an opportunity to grow fodder or grass on the riser, but they can also experience water-logging.

Table 2 | Socio- and physical characteristics of the study watersheds.

Features	Anjeni	Dijil	Debre Mewi
Size of watershed (ha)	113	936	523
Altitude (m.a.s.l)	2450	2480	2300
Average annual rainfall (mm)	1790	1300	1260
Dominant soil types	Alisols, Nitisols, Regosols, Leptisols	Nitisols	Vertic Nitisols, Nitisols, Vertisols
Degradation	Degraded	Very degraded	Not heavily degraded
Soil pH	5.7	4.3	6.7
Slope class			
Flat to gentle (<10%) (%)	30.5	13.9	19.7
Medium (10–20%) (%)	28.6	41.4	41.9
Steep (>20%) (%)	40.9	44.7	38.4
Dominant crop in farming systems	Barley	Oats	Tef
Productivity	Low	Low	High
Number of households	95	628	324
All weather road	Poor	Good	Good
Distance to district town (km)	20	8	12

Sources: SCRP, 1991; Liu et al., 2008; Zegeye, 2009; Tesfaye, 2011.

Stone bunds

Stone bunds are usually constructed where stones are readily available on or near the field. Stone bunds are stable and durable measures. They can reduce runoff and soil erosion in steeply sloping areas, and excess water can pass more easily through stone terraces. However, construction does require a large amount of labor. Furthermore, they are not convenient for ox-plowing and can harbor rodents.

No measures

The *No measure* is one of the options available in the farmers' SWC investment decision-making. This alternative would be preferred by farmers when SWC measures have minimal impacts (ecologically, economically, and socially).

DATA ANALYSIS

Data analysis included the ranking of the most important SWC alternatives and standardization of the effects. Average weightings were used in our analysis to accommodate the different views of the farmers and experts on the relative importance of each criterion. Farmers and experts evaluated SWC measures by giving scores to each criteria on a scale of 1 for worst and 4 for best (and 3 in case of Anjeni, where only three alternatives were considered). We used the mode (most typical value) to aggregate rankings of individual farmers and experts. Scoring of the alternatives was also calculated by averaging the scales to crosscheck the results.

Regime Analysis method was used to obtain a complete ranking and further detailed information on the relative importance between the alternatives (Hinloopen and Nijkamp, 1990). The Regime Analysis method is one of the most common weighting methods, particularly in the case of qualitative data. This method is used to analyse ordinal and cardinal data. This method is based on pairwise comparison of two alternatives *i* according to criteria *j* (Hinloopen and Nijkamp, 1990).

Consider two alternatives *i* and *i'*. The pairwise comparison of these two alternatives according to criterion *j* ($e_{ii',j}$) is therefore:

$$e_{ii',j} = 1 \text{ if } p_{ij} > p_{i'j} \quad (1)$$

$$e_{ii',j} = -1 \text{ if } p_{ij} < p_{i'j} \quad (2)$$

Where p_{ij} and $p_{i'j}$ are the ranks of alternatives *i* and *i'* according to criteria *j*. The regime vector ($e_{ii'}$) for each pair of alternatives is then constructed by extending the comparison of the alternatives

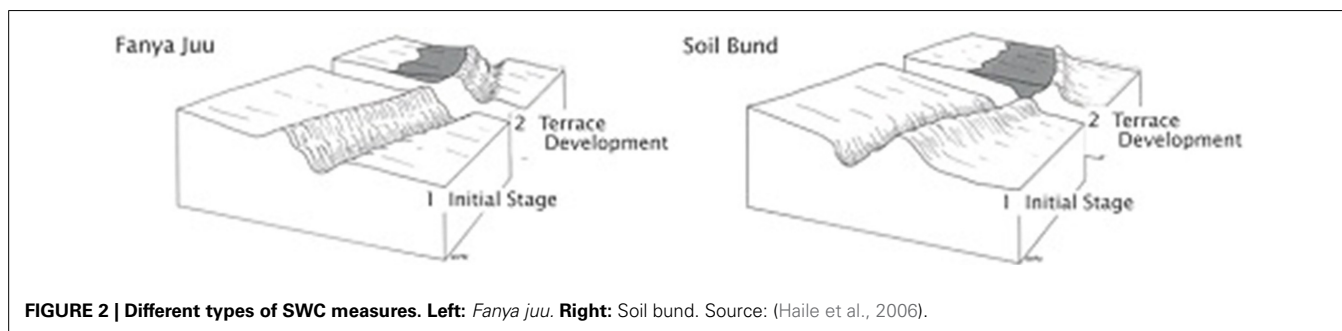


FIGURE 2 | Different types of SWC measures. Left: *Fanya juu*. Right: Soil bund. Source: (Haile et al., 2006).

i and i' to all criteria $j = 1, 2, \dots, J$ as follows:

$$e_{ii'} = (e_{ii',1}, e_{ii',2}, \dots, e_{ii',J}) \quad (3)$$

Positive “+” and negative “−” signs are used to indicate the relative dominance of one alternative over another, and “0” for no dominance. Based on the pairwise comparison of the alternatives obtained, the weighted dominance of alternative i with respect to i' ($p_{ii'}$) is defined as:

$$p_{ii'} = \sum_{j=1}^J w_j * e_{ii',j} \quad (4)$$

where

w_j = weight relative to criterion j ,

$e_{ii'}$ = pairwise comparison of alternative i and i' , and
 j = the criterion.

RESULTS

MAJOR ACTORS AND THEIR OBJECTIVES

Erosion has adverse impacts on ecological, economic, and social aspects of farming communities. Farmers evaluate these multiple effects of the problem in their SWC investment decisions. In our formal and informal surveys we found that the major objectives of farmers in relation to SWC investments are ecological restoration (erosion control, enhanced soil fertility and increased water retention), economic benefits (increase production and decrease costs), and diminishing socially adverse effects of erosion and SWC measures. Similarly, the major objective revealed from the experts is to improve the livelihood of the farmers through comprehensive and integrated natural resource management and development.

EVALUATION CRITERIA AND WEIGHTINGS

Farmers and experts defined and used 10 evaluation criteria to evaluate SWC measures, which were then categorized into ecological, economic, social, and other criteria (Table 3).

Ecological criteria

Three criteria were identified for evaluating the ecological impacts of SWC alternatives. The criteria reveal that farmers would like SWC measures that are effective in erosion control, enhance soil fertility and improve water retention.

Economic criteria

Four criteria were mentioned to evaluate the economic impact of SWC alternatives. These evaluation criteria focus on the costs and benefits aspects of SWC alternatives.

Social and other criteria

Farmers in the study areas predominantly preferred SWC measures that have social benefits as well as measures that have no adverse effects on the farming system.

Farmers and experts gave weightings for the different evaluation criteria (Tables 4, 5). The results show that farmers and experts gave different weights and that these vary by slope

category. The ecological impact criteria had the highest weighting within the steep slope category. On the other hand, economic impact criteria received the highest weighting in the gentle slope category. According to the farmers' views steeper slopes are more prone to erosion and that it is relatively more important to preserve them. The gentle plots, on the other hand, have higher economic potential.

Farmers gave relatively high scores to the social and other impacts criteria of SWC measures compared to the experts (Tables 4, 5). These criteria are: contributions of SWC measures to avoid disputes with adjacent farmers due to erosion, ox-plowing convenience of the measures and the risk of pest harboring effects of the measures. This shows that farmers pay more attention to everyday aspects of their lives during SWC investments while experts have larger scales than the field/farm, e.g., watershed level, in mind.

Anjeni farmers gave a higher weighting for maximizing crop yield, maximizing plowing convenience, and minimizing disputes with adjacent farmers as compared to other watersheds. This could be due to long term SWC activities implemented in the watershed within the last three decades and thereby farmers perceived the benefits of conservation measures over time. Most of the *Fanya juu* bunds in Anjeni have stabilized into bench terraces.

Table 3 | Farmers'/experts' evaluation criteria of SWC measures.

Objectives	Criteria	Unit of measurement
ECOLOGICAL IMPACTS		
Erosion control (C1)	Minimize soil loss	Rank
Enhance soil fertility (C2)	Minimize nutrient loss	Rank
Water retention (C3)	Maximize water retention	Rank
ECONOMIC IMPACTS		
Crop yields (C4)	Maximize crop yields	Rank
Grass production (C5)	Maximize grass production	Rank
Labor requirements for establishment (C6)	Minimize labor for establishment	Rank
Maintenance costs (C7)	Minimize maintenance costs	Rank
SOCIAL AND OTHER IMPACTS		
Ox-plowing convenience (C8)	Maximize ox-plowing convenience	Rank
Risk of pest harboring effect (C9)	Minimize risk of pest harboring effect	Rank
Avoid dispute with adjacent farmers (C10)	Minimize dispute with adjacent farmers	Rank

Source: Own surveys.

This results in the diminution of slope angles and increased topsoil depth behind the bunds, which has a positive effect on yields.

FARMERS AND EXPERTS MULTI-CRITERIA RANKING OF THE ALTERNATIVES

The results of farmers' and experts' ranking of SWC measures based on the evaluation criteria are presented in **Tables 6–8**. The scores indicate the perceived level of importance of each SWC alternative with respect to the criteria defined.

Farmers and experts ranked stone bunds first for erosion control in the steep slope category in the three watersheds, while soil bunds are preferred by experts and farmers in Debre Mewi and Dijil watershed to control erosion in the moderate slope category. Soil bunds are not common practice in Anjeni watershed, but regardless, farmers selected *Fanya juu* bunds to control erosion in the moderate slope category. In all watersheds, farmers gave priority to *Fanya juu* bunds to control erosion in gentle slope areas. Farmers' rankings of SWC alternatives for maximizing crop yield were highly correlated with the degree of erosion control of the measures, except for *Fanya juu* in Debre Mewi. Even though *Fanya juu* bunds were preferred to control erosion on gentle slopes, their contribution to increased yield was not ranked as high, probably due to the water logging effects of the measures in Debre Mewi (**Tables 6–8**).

Farmers did not prefer stone bunds due largely to high labor demands for establishment, plowing inconvenience and the risks of pest harboring effects, as evident across all watersheds and slope categories (**Tables 6, 7**). Soil bunds were next to “no measure” ranked first in minimizing labor requirements for establishment of SWC. On the other hand, it was ranked last in minimizing maintenance costs. In general, farmer preferences reflect their experiences, perceptions, and attitudes about the merits and drawbacks of SWC alternatives under different situations.

THE EVALUATION MATRIX

Pairwise comparisons refine a complex decision problem into a series of one-to-one judgments regarding the significance of each

alternative relative to the criterion that it describes (Balana et al., 2010). A pairwise comparison of the SWC alternatives against the evaluation criteria is presented in **Table 9**. Each alternative under a given criterion is compared with every other alternative under that criterion to evaluate its relative importance.

RANKING OF THE ALTERNATIVES

The weighted scores (p) of the pairwise comparisons and overall rank of the alternatives for each slope category are given in **Tables 10, 11**. The higher the evaluation score, the better the perceived performance of the SWC alternative. The evaluation score of each alternative pair in descending order provides a list of SWC measure from best to worst performing.

Steep slope category

In steeply sloping areas, stone bunds are the most viable SWC alternative in all watershed areas, followed by soil bunds. Stone bunds are durable and stable in controlling high runoff in steep areas. Stone bunds are also the first alternative for experts. Other SWC measures are easily eroded by runoff. Farmers

Table 5 | Experts' weighting (%) sets of evaluation criteria for each slope category.

Criteria	Slope		
	Steep	Moderate	Gentle
Erosion control	30.4	21.4	10
Enhance fertility	15.7	14.1	9.9
Water retention	13.1	11.4	14.7
Crop yields	12.6	21.2	30.2
Grass production	9.5	8.1	5.5
Labor for establishment	3.5	7.1	10.9
Maintenance cost	3.9	6.1	7.5
Plowing convenience	2.1	4.2	5.9
Pest harboring effect	2.8	3.5	4.3
Dispute with adjacent farmers	5.9	2.9	1.1
Total (%)	100	100	100

Table 4 | Farmers' weight sets of evaluation criteria for each slope category in percentages.

Criteria	Steep slope			Moderate slope			Gentle slope		
	D. Mewi	Anjeni	Dijil	D. Mewi	Anjeni	Dijil	D. Mewi	Anjeni	Dijil
Erosion control	30.0	31.0	30.0	20.0	18.0	22.5	7.7	5.0	5.5
Enhance fertility	16.6	14.0	16.0	12.3	9.0	12.5	7.0	6.0	13.5
Water retention	11.7	10.0	9.0	11.0	13.0	10.0	15.3	14.0	13.5
Crop yields	13.3	14.0	15.0	23.3	27.6	25.0	30.0	35.0	32.5
Grass production	7.7	6.6	7.5	5.3	3.8	3.5	3.3	3.2	2.5
Labor for establishment	3.0	3.1	2.25	8.0	5.8	5.0	13	10.1	7.5
Maintenance cost	2.7	3.3	2.75	5.0	5.8	4.0	8.7	8.7	7.5
Plowing convenience	2.3	2.6	2.25	5.3	5.6	4.5	7.7	8.8	8.5
Pest harboring effect	3.0	3.4	2.75	3.7	3.8	4.5	4.3	5.6	5.5
Dispute with adjacent farmers	9.7	12.0	12.5	6.0	7.6	8.5	3.0	3.6	3.5
Total (%)	100	100	100	100	100	100	100	100	100

Table 6 | Farmers' ranking of SWC measures on the evaluation criteria for different slopes (4, Best; 1, Worst): Debre Mewi and Dijil watersheds.

Criteria	Slope	Watershed	Soil bund	<i>Fanya juu</i>	Stone bund	No measure
Minimize soil losses(erosion control)	Steep	Debre Mewi	3	2	4	1
		Dijil	3	2	4	1
	Moderate	Debre Mewi	4	2	3	1
		Dijil	4	3	2	1
	Gentle	Debre Mewi	3	4	2	1
		Dijil	3	4	2	1
Enhance soil fertility	Steep	Debre Mewi	3	2	4	1
		Dijil	3	2	4	1
	Moderate	Debre Mewi	4	3	2	1
		Dijil	3	4	2	1
	Gentle	Debre Mewi	3	4	2	1
		Dijil	3	4	2	1
Maximize water retention	Steep	Debre Mewi	4	3	2	1
		Dijil	4	2	3	1
	Moderate	Debre Mewi	3	4	2	1
		Dijil	3	4	2	1
	Gentle	Debre Mewi	3	4	2	1
		Dijil	3	4	2	1
Maximize crop yields	Steep	Debre Mewi	3	2	4	1
		Dijil	3	2	4	1
	Moderate	Debre Mewi	4	3	2	1
		Dijil	3	4	2	1
	Gentle	D. Mewi	4	3	2	1
		Dijil	3	4	2	1
Maximize fodder (grass) production	Steep	Debre Mewi	3	4	1	1
		Dijil	3	4	1	1
	Moderate	Debre Mewi	3	4	1	1
		Dijil	3	4	1	1
	Gentle	Debre Mewi	3	4	1	1
		Dijil	3	4	1	1
Minimize labor requirement for establishment	Steep	Debre Mewi	3	2	1	4
		Dijil	3	2	1	4
	Moderate	Debre Mewi	3	2	1	4
		Dijil	3	2	1	4
	Gentle	Debre Mewi	3	2	1	4
		Dijil	3	2	1	4
Minimize maintenance costs	Steep	Debre Mewi	1	2	3	4
		Dijil	1	2	3	4
	Moderate	Debre Mewi	1	2	3	4
		Dijil	1	2	3	4
	Gentle	Debre Mewi	1	2	3	4
		Dijil	1	2	3	4
Maximize ox-plowing convenience	Steep	Debre Mewi	3	2	1	4
		Dijil	3	2	1	4
	Moderate	Debre Mewi	3	2	1	4
		Dijil	3	2	1	4
	Gentle	Debre Mewi	3	2	1	4
		Dijil	3	2	1	4

(Continued)

Table 6 | Continued

Criteria	Slope	Watershed	Soil bund	<i>Fanya juu</i>	Stone bund	No measure
Minimize risks of pest harboring effect	Steep	Debre Mewi	2	3	1	4
		Dijil	3	2	1	4
	Moderate	Debre Mewi	2	3	1	4
		Dijil	3	2	1	4
	Gentle	Debre Mewi	2	3	1	4
		Dijil	3	2	1	4
Minimize dispute with adjacent farmers	Steep	Debre Mewi	3	2	4	1
		Dijil	3	2	4	1
	Moderate	Debre Mewi	4	3	3	1
		Dijil	4	3	2	1
	Gentle	Debre Mewi	4	3	2	1
		Dijil	3	4	2	1

Table 7 | Farmers' ranking of SWC measures on the evaluation criteria for different slopes (3, Best; 1, Worst): Anjeni watershed.

Criteria	Slope	<i>Fanya juu</i>	Stone bund	No measure
Minimize soil losses (erosion control)	Steep	2	3	1
	Moderate	3	2	1
	Gentle	3	2	1
Enhance soil fertility	Steep	2	3	1
	Moderate	3	2	1
	Gentle	3	2	1
Maximize water retention	Steep	3	2	1
	Moderate	3	2	1
	Gentle	3	2	1
Maximize crop yields	Steep	2	3	1
	Moderate	3	2	1
	Gentle	3	2	1
Maximize fodder (grass) production	Steep	3	1	1
	Moderate	3	1	1
	Gentle	3	1	1
Minimize labor requirement for establishment	Steep	2	1	3
	Moderate	2	1	3
	Gentle	2	1	3
Minimize maintenance costs	Steep	1	2	3
	Moderate	1	2	3
	Gentle	1	2	3
Maximize ox-plowing convenience	Steep	2	1	3
	Moderate	2	1	3
	Gentle	2	1	3
Minimize risks of pest harboring effect	Steep	2	1	3
	Moderate	2	1	3
	Gentle	2	1	3
Minimize dispute with adjacent farmers	Steep	2	3	1
	Moderate	3	2	1
	Gentle	3	2	1

Table 8 | Experts' ranking of SWC measures on the evaluation criteria for different slopes (4, Best; 1, Worst).

Criteria	Slope	Soil bund	<i>Fanya juu</i>	Stone bund	No measure
Minimize soil losses (erosion control)	Steep	3	2	4	1
	Moderate	4	3	2	1
	Gentle	3	4	2	1
Enhance soil fertility	Steep	3	2	4	1
	Moderate	4	3	2	1
	Gentle	3	3	2	1
Maximize water retention	Steep	3	3	3	1
	Moderate	3	3	2	1
	Gentle	3	4	2	1
Maximize crop yields	Steep	3	2	4	1
	Moderate	4	3	2	1
	Gentle	3	4	2	1
Maximize fodder (grass) production	Steep	4	3	1	1
	Moderate	3	4	1	1
	Gentle	3	4	1	1
Minimize labor requirement for establishment	Steep	3	2	1	4
	Moderate	3	2	1	4
	Gentle	3	2	1	4
Minimize maintenance costs	Steep	2	2	3	4
	Moderate	2	2	3	4
	Gentle	2	2	3	4
Maximize ox-plowing convenience	Steep	3	2	1	4
	Moderate	3	2	1	4
	Gentle	3	2	1	4
Minimize risks of pest harboring effect	Steep	3	2	1	4
	Moderate	3	2	1	4
	Gentle	3	2	1	4
Minimize dispute with adjacent farmers	Steep	3	2	4	1
	Moderate	4	3	2	1
	Gentle	3	3	2	1

and experts ranked *Fanya juu* as the least effective alternative next to “No measures” in steeply sloping areas, as high runoff would easily rupture these structure. Thus, the main objective of farmers in steep areas is to control erosion and consequently, farmers know that stone bunds are the most effective measure.

Moderate slope category

For moderate sloping areas, soil bunds are the best alternative for farmers (Debre Mewi) and experts; however in the Dijil and Anjeni areas, *Fanya juu* is preferred. As water erosion is not as severe on moderate slopes, soil embankments are deemed a suitable measure. Farmer weightings also indicate that increasing yields represents the main objective on moderate slopes (Table 4).

Gentle slope category

Fanya juu bunds were the most preferred alternative on plots with gentle slopes in Dijil and Anjeni but not in the Debre Mewi watershed. Farmers invest in SWC on gentle sloped areas to increase production and productivity to help achieve higher profitability for their practice; similar to the moderate slope category. Farmers of Debre Mewi preferred soil bunds for moderate and gentle slopes categories due to their long time experience with soil bunds (Table 11).

DISCUSSION

There are differences between the weight sets of farmers and those of experts. Farmers in the three watersheds give social and other criteria on all three slope categories a weighting of about 17%, while this is only 11% among experts. The latter underestimate

Table 9 | Pairwise comparison of SWC measures based on the evaluation criteria (from Table 3).

(A) FARMERS IN Debre Mewi WATERSHED																															
Regime vector	Steep slope										Moderate slope										Gentle slope										
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	
e-12	1	1	1	1	-1	1	-1	1	-1	1	1	1	-1	1	-1	1	-1	1	-1	1	-1	-1	-1	1	-1	1	-1	1	-1	1	
e-13	-1	-1	1	-1	1	1	-1	1	1	-1	1	1	1	1	1	1	-1	1	1	1	1	1	1	1	1	1	1	-1	1	1	
e-14	1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	1	1	1	-1	-1	1	1	
e-23	-1	-1	1	-1	1	1	-1	1	1	-1	-1	1	1	1	1	1	-1	1	1	0	1	1	1	1	1	1	1	-1	1	1	
e-24	1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	1	1	1	-1	-1	1	1	
e-34	1	1	1	1	0	-1	-1	-1	-1	1	1	1	1	1	0	-1	-1	-1	-1	1	1	1	1	1	1	0	-1	-1	-1	1	
(B) FARMERS IN Anjeni WATERSHED																															
e-12	-1	-1	1	-1	1	1	-1	1	1	-1	1	1	1	1	1	1	-1	1	1	1	1	1	1	1	1	1	1	-1	1	1	
e-13	1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	1	1	1	-1	-1	1	1	
e-23	1	1	1	1	0	-1	-1	-1	-1	1	1	1	1	1	0	-1	-1	-1	-1	1	1	1	1	1	1	0	-1	-1	-1	1	
(C) FARMERS IN Dijii WATERSHED																															
e-12	1	1	1	1	-1	1	-1	1	1	1	1	-1	-1	-1	1	-1	1	1	1	1	-1	-1	-1	-1	1	-1	1	1	-1	1	
e-13	-1	-1	1	-1	1	1	-1	1	1	-1	1	1	1	1	1	1	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	
e-14	1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	1	1	1	-1	-1	1	1	
e-23	-1	-1	-1	-1	1	1	-1	1	1	-1	1	1	1	1	1	1	-1	1	1	1	1	1	1	1	1	1	-1	1	1	1	
e-24	1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	1	1	1	-1	-1	-1	1	
e-34	1	1	1	1	0	-1	-1	-1	-1	1	1	1	1	1	0	-1	-1	-1	-1	1	1	1	1	1	1	0	-1	-1	-1	1	
(D) EXPERTS																															
e-12	1	1	0	-1	1	1	0	1	1	-1	1	1	0	1	-1	1	0	1	1	1	-1	0	-1	-1	-1	1	0	1	1	0	
e-13	-1	-1	0	1	-1	1	-1	1	1	1	1	1	1	1	1	1	-1	1	1	1	1	1	1	1	1	1	-1	1	1	1	
e-14	1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	1	1	1	-1	-1	1	1	
e-23	-1	-1	0	1	-1	1	-1	1	1	1	1	1	1	1	1	1	-1	1	1	1	1	1	1	1	1	1	1	-1	1	1	
e-24	1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	1	1	1	-1	-1	1	1	
e-34	1	1	1	1	0	-1	-1	-1	-1	1	1	1	1	1	0	-1	-1	-1	-1	1	1	1	1	1	1	0	-1	-1	-1	1	

Table 10 | The weighted scores of the pairwise comparisons and overall rank (Rk) of the alternatives for each slope category, by watershed and for farmers and experts.

R.S	Ranking by farmers						Ranking by experts			Ranking by farmers		
	Debre Mewi watershed			Dijil watershed			All watersheds			Anjeni watershed		
	S	M	G	S	M	G	S	M	G	S	M	G
p12	73.2	49.9	7.4	79.5	−10.0	−57.0	45.5	60.5	−39.3	−48.6	88.4	82.6
p13	−44.6	89.9	82.6	−52.5	92.0	85.0	−32.6	87.8	85	75.2	58.0	33.6
p14	78.0	55.9	32.6	80.0	64	42.0	74.9	58.2	42.8	68.6	54.2	30.4
p23	−44.6	43.9	82.6	−70.5	70.5	70.5	−32.6	87.8	85			
p24	78.0	55.9	32.6	80.0	64	42.0	74.9	58.2	42.8			
p34	70.3	50.6	29.3	72.5	60.5	39.5	65.4	50.1	37.3			
Rk	3>1 > 2>4	1>2 > 3>4	1>2 > 3>4	3>1 > 2>4	2>1 > 3>4	2>1 > 3>4	3>1 > 2>4	1>2 > 3>4	2>1 > 3>4	2>1 > 3	1>2 > 3	1>2 > 3

Table 11 | MCA ranking of the SWC measures by farmers and experts.

Watershed	Slope	Ranking
RANKING BY FARMERS		
Debre Mewi	Steep	Stone bunds > soil bunds > <i>Fanya juu</i> > no measure
	Moderate	Soil bunds > <i>Fanya juu</i> > stone bunds > no measure
	Gentle	Soil bunds > <i>Fanya juu</i> > stone bunds > no measure
Anjeni	Steep	Stone bunds > <i>Fanya juu</i> > no measure
	Moderate	<i>Fanya juu</i> > stone bunds > no measure
	Gentle	<i>Fanya juu</i> > stone bunds > no measure
Dijil	Steep	Stone bunds > soil bunds > <i>Fanya juu</i> > no measure
	Moderate	<i>Fanya juu</i> > soil bund > stone bund > no measure
	Gentle	<i>Fanya juu</i> > soil bund > stone bund > no measure
RANKING BY EXPERTS		
All watersheds	Steep	Stone bund > soil bund > <i>Fanya juu</i> > no measure
	Moderate	Soil bund > <i>Fanya juu</i> > stone bund > no measure
	Gentle	<i>Fanya juu</i> > soil bund > stone bund > no measure

the issues of ease of plowing, pest harboring effects, and disputes. The experts on the other hand attach higher weighting to the three ecological criteria and to earnings from grass production; aspects which they focus on in their extension messages. This is in line with the findings of Tenge (2005).

The results of the analysis also illustrate that farmers often stick to practices that they are more familiar with. In Debre Mewi, farmers on moderate and gentle slopes prefer soil bunds above *Fanya juu*, since they have become accustomed to soil bunds and not (yet) to *Fanya juu*. In Anjeni and (to a lesser extent) Digil, farmers already have lengthy (over 30 years) experience with *Fanya juu* and therefore prefer this SWC measure on

moderate and gentle slopes. It is interesting to note that among the experts, there was one favorite measure for each slope category: stone bunds for steep slopes, soil bunds for moderate slopes and *Fanya juu* for gentle slopes. But experts should still look at each particular situation and should not come up with rigid guidelines.

Farmers take into account ecological, economic, social, and other impacts of the SWC when they select SWC practices to meet multiple objectives. Thus, adoption of SWC practices by farmers is not solely based on economic or monetary values as usually demonstrated through CBA (Tenge, 2005; Amsalu, 2006). This suggests that SWC practices that fulfill both economic and other considerations of farmers can contribute to the continued adoption of SWC.

Furthermore, this study revealed that SWC practices have ecological, economic and social benefits. However, SWC practices are mostly evaluated by CBA. These SWC practices are sometimes not profitable from a private-economic point of view (Kassie et al., 2011; Adimassu et al., 2012). This is because the ecological and social benefits of SWC practices they are not quantified in monetary values. Thus, holistic evaluation methods (e.g., MCA) are important to evaluate the overall benefits of SWC practices. Moreover, MCA accommodates diverse views, interests, preferences, and expertise of the stakeholders (Balana et al., 2010). However, MCA with ordinal data does not incorporate the time dimension of costs and benefits, which is pertinent for SWC measures that need a long time for benefits to be realized. The time dimension of SWC can be incorporated within MCA through the use of an efficiency criteria of CBA. The following describes such an example.

Undertaking a CBA for a standard slope of 10%, with an assumed 20 years lifetime of the measures and a 12.5% discount rate, it was found that in Debre Mewi soil bunds (with grassed risers) and stone bunds had a Net Present Value (NPV) of 1819 and 1265 EtB ha^{−1} over 20 years, respectively (1 EtB ≈ 0.056 \$US in 2013). Since *Fanya Juu* was only recently introduced in the Debre Mewi watershed, it was not taken into account. In the Anjeni watershed, soil bunds (rare in this watershed), *Fanya juu* (both with grassed risers) and stone bunds, scored a NPV of 1902, 2718, and 2217 EtB ha^{−1}, respectively (Teshome et al., 2013). Since

these detailed calculations were only made for the most common slopes of 10%, these results can only be used for the moderate slope category, for two watersheds and three SWC alternatives. This information on financial efficiency (expressed by NPV) was subsequently used for the economic impact within the Regime Analysis (replacing the four separate cost and benefit criteria). The information on the other (ecological and social/other) evaluation criteria remained the same. The results of this analysis show the same ranking as in the previous analysis for the moderate slopes in the two watersheds: soil bunds better than stone bunds in Debre Mewi watershed and *Fanya juu* better than stone bunds in Anjeni watershed. The measures were in both cases better than no measure.

CONCLUSIONS

A number of SWC practices in the north-western highlands of Ethiopia using MCA were evaluated to assess their ecological, economic and social impacts. The study revealed that MCA is an effective evaluation tool that can take into account non-monetary and less quantifiable effects of SWC measures, which is not possible with a CBA.

The results of the analysis indicate that farmers in the north-western highlands of Ethiopia have a range of criteria to evaluate the performance of SWC measures. The relative importance of each criterion in the selection of SWC alternatives depends to a large extent on slope categories. Farmers in the study areas gave the highest score for criteria related to ecological impacts in steeply sloping areas, and prefer alternatives with stronger positive economic impacts in moderate and gentle sloping areas. Furthermore, stone bunds were deemed the best SWC alternative on steep slopes in all watersheds. *Fanya juu* bunds are the most preferred alternative on plots with gentle slopes in the Dijil and Anjeni watersheds. This indicates that SWC alternatives must be promoted based on farmers' preferences and specific agro-ecological conditions such as slope. Thus, in order to facilitate the adoption of SWC practices, a blanket recommendation approach must be avoided. The extension service should deliver a range of SWC options for the needy farmers from which to select an appropriate SWC measure that is governed by their preferences and plot situation. In addition, the Research-Extension-Farmers linkage must be strengthened in order to identify and disseminate appropriate technologies based on farmer needs. To conclude, policy makers and development practitioners should pay more attention to farmer SWC preferences and particular circumstances (e.g., slope) in designing SWC strategies and programmes.

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